P-24: Plasma Physics

Kurt F. Schoenberg, Group Leader
Juan C. Fernández, Deputy Group Leader

Introduction

The Plasma Physics Group (P-24) researches the basic properties of plasmas with a view to applications in important Los Alamos National Laboratory and national programs. Plasmas occur in nature when matter exceeds temperatures of roughly 10,000° C. At these temperatures, the constituent atoms and molecules of matter begin to lose their bound electrons to form a substance composed of positive or negative ions and free electrons. All principal phenomena in plasmas can be traced to the fact that ions and electrons interact with each other through long-range electromagnetic forces. The electromagnetic interactions of groups of charged particles are often coherent, leading to collective modes of plasma behavior. This collective interaction of charged particles, a many-body problem, is the essence of the field of plasma physics.

Roughly 99% of the matter in the universe is in a plasma state. Plasmas can exist over a large range of temperatures and densities. For example, interstellar space contains plasmas with densities of less than one ion or electron per cubic meter at temperatures exceeding 1,000° C. In contrast, plasmas created by intense laser compression of micropellets achieve densities up to 10^{26} ions or electrons per cubic centimeter at temperatures exceeding 10,000,000° C. The understanding and application of such diverse plasmas is a Los Alamos core competency.

P-24 is composed of a diverse technical staff with expertise in plasma physics, plasma chemistry, atomic physics, laser and optical science, pulsed power, dynamic properties of materials, and transient radiation and particle diagnostics. The group uses both on-site and off-site experimental facilities to address problems of national significance in inertial and magnetic fusion, high-energy-density physics, conventional defense, environmental management, and plasma-based advanced or environmentally friendly manufacturing. Our agenda includes basic research in the properties of energetic matter and applied research that supports the principal Laboratory mission of enhancing global nuclear security. The pursuit of this agenda entails the physics of plasmas over a wide and diverse range of conditions, as shown in Figure 1.

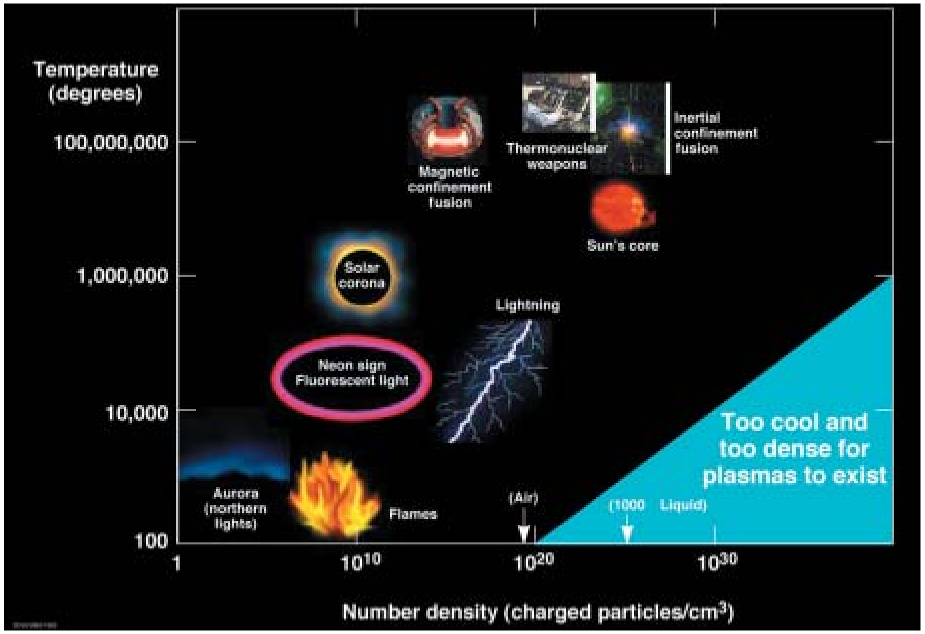

Figure 1. As this illustration of the plasma state shows, the physics of plasmas entails a wide and diverse range of conditions. (Illustration courtesy of Dr. Don Correll, Lawrence Livermore National Laboratory).

Trident Laser Facility

Trident is the multipurpose laboratory at Los Alamos for conducting experiments requiring high-energy laser-light pulses. As a user facility, it is operated by P-24 primarily for inertial confinement fusion (ICF) research, high-energy-density physics, and basic research. Features include flexible driver characteristics and illumination geometries, a broad resident diagnostic capability, and flexible scheduling. A dedicated staff maintains and operates the facility and assists visiting experimenters. Target fabrication is supported by the Laboratory's Target-Fabrication Facility in the Materials Science and Technology (MST) Division.

The principal resource at Trident is the laser driver (Figure 2). It employs a neodymium-doped, yttrium-lithium-fluoride (Nd:YLF) master oscillator and a chain of Nd:phosphate glass-rod and disk amplifiers in a conventional master-oscillator, power amplifier architecture. The oscillator output pulse is temporally shaped, amplified, split into two beams, amplified again, frequency-doubled, transported, and focused onto the target. A third beam line

Figure 2. Laser driver of the Trident laser facility.

can be used as an optical probe or to provide an x-ray backlighting capability. Its pulse can be either 100 ps in length or the same length and shape as those of the main drive beams. Although the third beam line is normally operated at 527 nm, it can also be operated at 1,054 nm or 351 nm (fundamental and third harmonic output, respectively). The third beam can be timed to become active before or up to 5 ns after the main drive beams. The output of the master oscillator may also be frequency-broadened and "chirped" before amplification to allow compression to subpicosecond pulse lengths. Although normal operation relies on pulse lengths of order 1 ns, pulse lengths for specialized applications (such as dynamic materials experiments) have exceeded 100 ns.

The south high-vacuum target chamber is a cylinder approximately 150-cm long and 75 cm in diameter. Single- or double-sided illumination of targets is possible through several 20-cm-diameter ports on each end of the chamber. More than 40 smaller ports are available for diagnostic instrumentation. Individual targets are inserted through an airlock. The target insertion and positioning mechanism provides *x-y-z* and rotation adjustment under computer control with 1-μm linear and 0.01° angular resolution. The three-axis target-viewing system has a 20-μm resolution. The chamber is fitted with a Nova standard six-inch instrument manipulator (SIM) to accept all SIM-based instruments for checkout, characterization, or use. Trident is located in an area of the Laboratory that can accommodate both unclassified and classified research.

The north high-vacuum target chamber has just become available for experiments. It is a spherical stainless steel chamber, 3" thick and 63.25" outside diameter. It is capable of very flexible target illumination and diagnostic placement due to the 92 ports of various sizes available around the chamber surface. At present, laser illumination at the north chamber is available at 1,054 nm only, but the beam transport and alignment systems for 351 nm are being designed. The chamber has just been fitted with a brand new diagnostic manipulator of the latest generation: the ten-inch instrument manipulator (TIM) in use at the Omega laser facility at the University of Rochester. The TIM can also accept the earlier-generation SIM-based instruments. We also have in house the prototype for the diagnostic insertion manipulator (DIM) for the National Ignition Facility (NIF), designed and built in the United Kingdom (UK) by the Atomic

Weapons Establishment (AWE). In the near future it will be mated to the north chamber to allow the ICF community to test DIM-based NIF diagnostics, a unique capability that Trident will provide.

Optical diagnostics routinely used at Trident include illumination and backscattered-light calorimeters, backscattered-light spectrometers, and high-bandwidth (5-GHz) and streak-camera-based power monitors. Target x-ray emission is monitored by filtered, photoconductive diamond detectors and an x-ray streak camera with <10-ps resolution. Gated, filtered x-ray images covering 1 ns in 16 images are provided with 80-ps resolution by a SIM-based standard gated x-ray imager. Various filtered x-ray power and spectral diagnostics can be installed as needed. These cover the energy range of 0–35 keV. Static x-ray pinhole cameras are also available. Both point and line VISAR (velocity interferometer system for any reflector) diagnostics are now being used for selected experiments. Most optical and target diagnostics are available for either the main target chambers or the ultrahigh-irradiance chamber.

As a user facility, Trident is available to both Laboratory and outside experimenters. The quality of proposed research and its relevance to Laboratory missions are major criteria in determining what experiments are fielded. Trident is operated by P-24 as a user facility that principally supports the Inertial Confinement Fusion and Radiation Physics (ICF&RP) program as well as other programs in the Nuclear Weapons Directorate. It is funded through and operated for the ICF&RP Program Office. The resources of the Laboratory's Target-Fabrication Facility, operated by MST Division, are also available to assist experimenters in designing, fabricating, and characterizing targets for Trident experiments.

In the long term, we intend to upgrade the Trident laser using refurbished Nova laser components, contingent on available funding. This upgraded laser system would be based on a multipass architecture with Nova 31.5-cm disk amplifiers. This new laser system would eventually include eight beam lines operating at 700 J each in 1 ns at 351 nm. Trident, in both its present and upgraded configurations, is envisioned to remain a very flexible, high-shot-rate facility that provides a staging capability to higher energy facilities such as Omega, the future NIF, and the Z pulsed-power machine at Sandia National Laboratories (Sandia). It will also allow us to continue performing experiments in laser-matter interactions and other fundamental science topics, and it will serve as an attractor for high-quality scientific research relevant to ICF and stockpile stewardship.

Inertial Confinement Fusion

The ICF&RP program at Los Alamos is a principal component of the national ICF program. A principal focus of the national program is the goal of achieving thermonuclear ignition in the laboratory, one of the grand scientific challenges of our time. This goal is part of the broader mission to provide scientific knowledge, experimental facilities, and technological expertise to support the Department of Energy (DOE) Stockpile Stewardship Management Plan for nuclear weapons. In pursuit of the ICF mission, P-24 designs, diagnoses, executes, and analyzes the results from experiments at high-energy laser facilities worldwide. P-24 partners with other Los Alamos groups that focus on theory, modeling, and target fabrication to execute the program, with the ultimate goal of understanding laser-matter interaction physics.

NIF is a state-of-the-art laser facility presently under construction at Lawrence Livermore National Laboratory (Livermore) (see Figure 3), at a cost of billions of dollars. It will be the world's most powerful laser by far and the principal focus of the national ICF program. Los Alamos and Sandia have been participating with Livermore in the design and construction of special equipment for this immense laser facility, which will be ≈300 ft × 500 ft upon completion and operate at an energy of 1.8 MJ at a major wavelength of 351 nm.

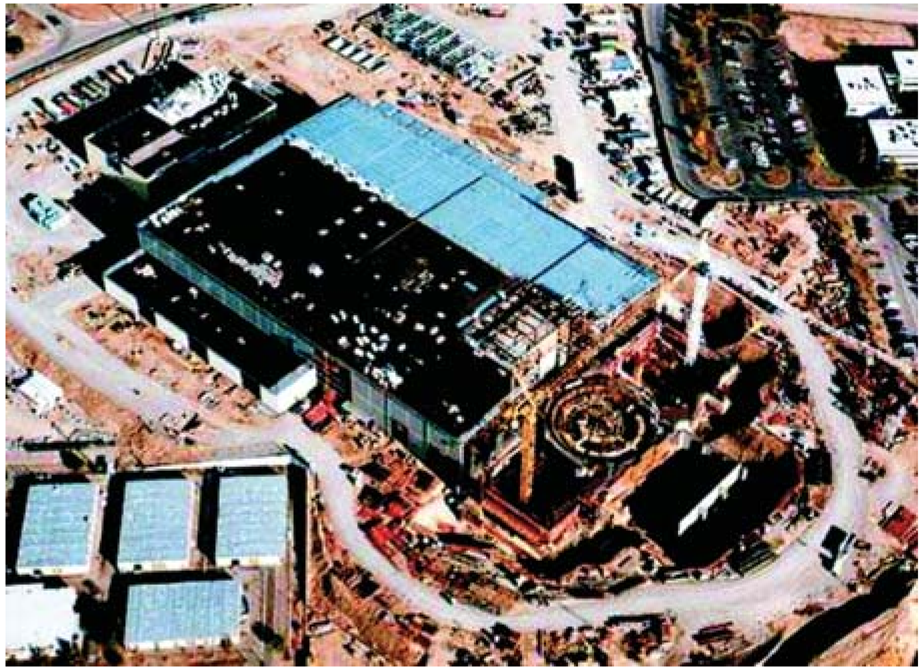

Figure 3. Arial view of the National Ignition Facility, a state-of-the-art, $1.2B laser facility presently under construction at Lawrence Livermore National Laboratory. The facility will be a key component in the national ICF program, which aims at achieving thermonuclear ignition in a laboratory setting.

In the early 1990s, Los Alamos scientists collaborated with other members of the national ICF program to establish the functional requirements and primary criteria that are the basis for this facility. Los Alamos scientists and engineers have been participating since fiscal year 1993 in the conceptual, preliminary, and detailed designs of a variety of NIF subsystems. P-24 is also a principal participant in the NIF Joint Central Diagnostic Team, and P-24 personnel have worked on the conceptual design for the 351-nm power and energy diagnostics, the preliminary design of a time-resolved x-ray imaging system, and various radiation and particle diagnostics of fusion. In addition, P-24 personnel have been involved with the management of this collaborative project.

NIF is a flexible laser, capable of greatly advancing both the ignition and weapons-physics missions. NIF is designed to drive a capsule filled with deuterium-tritium fuel to thermonuclear ignition by one of two distinct methods: direct or indirect drive. Direct drive involves the implosion of a capsule that is directly illuminated by the laser beams. Indirect drive involves laser illumination of the interior walls of a cavity (called a hohlraum) that contains the capsule. The hohlraum converts the laser energy into x-rays, which illuminate and implode the capsule very symmetrically, analogous to the process of baking an object evenly in an oven. Because both methods have different potential failure modes, both are being pursued to increase the likelihood of achieving ignition on NIF.

Considerable challenges face us in preparation for achieving fusion ignition on NIF, which will first be attempted using indirect drive. These challenges include developing novel diagnostic methods and instruments and improving our understanding in several scientific areas, including laser-plasma instabilities, hydrodynamic instabilities, hohlraum dynamics, and dynamic properties of materials. P-24 has contributed significantly in all of these areas with target-physics experiments using present and past lasers: Nova at Livermore, Omega Upgrade at the University of Rochester, and Trident at Los Alamos. For selected dynamic materials experiments, P-24 is also making use of the Z facility at Sandia.

P-24 personnel have devoted considerable effort over time to studying laser-plasma parametric instability (LPI) processes. We are focused presently on stimulated Raman scattering (SRS) and on the novel phenomena of beam deflection by plasma flow. LPIs pose a significant threat to ignition hohlraums because they could potentially scatter most of the laser light, decreasing both the drive efficiency and the capsule-illumination symmetry. In the recent past, P-24 has pursued a dual-track strategy of complementary experimental campaigns at Nova and Trident. P-24 researchers have applied the extensive Nova diagnostic suite on ignition-relevant hohlraums designed at Los Alamos, the most NIF-like plasmas ever made. The LPI experiments on Nova are now complete, and much of the data analysis has been finished and published. For more information, please read the research highlight "Laser Plasma Interactions in a Single Hot Spot" in Chapter 2. The resulting extensive LPI database has been invaluable in framing the important physics issues, guiding theoretical modeling and further experiments.

Our LPI experimental thrust has shifted to the application of new state-of-the-art capabilities and diagnostics on Trident long-scale NIF-relevant plasmas to allow more detailed measurements and comparisons of theory with experiment. These new capabilities include a nearly diffraction-limited interaction beam capable of the intensity range relevant to parametric instabilities in ignition-hohlraum plasmas. The use of a diffraction-limited interaction beam has proven to be a new paradigm in LPI experiments. It has allowed a whole new class of experiments where the results can be interpreted unambiguously to differentiate alternative theoretical possibilities, which is impossible when a conventional, speckled laser beam is used for interaction experiments. Imaging Thomson scattering now yields direct measurements of the spatial profile of important plasma parameters, such as electron density and temperature, ion temperature, plasma-flow velocity, and the location of the electrostatic waves responsible for laser scattering. We now can thoroughly benchmark the radiation-hydrodynamic codes used to design the plasma conditions in the first place.

The coupling of these recent diagnostics with reflected and transmitted beam diagnostics has allowed unprecedented studies of the time evolution of parametric instabilities and beam deflection. For example, in the context of our beam deflection experiments, Trident has provided (to our knowledge) the first quantitative detailed comparison between modeling and experiment on laser filamentation, to find that fluid plasma modeling coupled to an appropriate heat conduction model are sufficient to describe the phenomenon. We are exploiting the fact that the single-hot-spot Trident system is sufficiently small for direct modeling by an emerging suite of codes incorporating new theoretical models. At this point, for example, we know that kinetic effects are necessary to understand the evolution of SRS in long-scale NIF-relevant plasmas. Using kinetic models, a prediction for a new type of back-scattering process was verified experimentally. Ultimately we hope to gain sufficient understanding to develop simplified "reduced-description" models that are suitable for NIF-scale plasmas.

P-24 personnel have had important successes in advancing our understanding and capabilities in hohlraum dynamics. Based on experiments we have fielded in the recent past, we have become fairly confident in our understanding of the capabilities of cylindrical hohlraums, which will be used in the first indirect-drive ignition attempts on NIF, provided that we stay away from the regime of strong laser backscattering due to parametric instabilities. On Nova, we demonstrated control of beam deflection and its effects on capsule-illumination symmetry by spatial smoothing of the laser beam. On Omega Upgrade, we collaborated with Livermore researchers in an important experimental series that exploited the larger number of Omega beams to demonstrate the use and understanding of "beam phasing," in which beams are arranged into multiple beam cones, forming multiple rings of beam spots on the inner surface of a cylindrical hohlraum. Beam phasing will be necessary on NIF to tune both the time-integrated and time-dependent capsule-flux asymmetry by adjustment of the beam pointing and the power history in the different rings.

We have also demonstrated unprecedented time-integrated illumination symmetry using an advanced hohlraum design developed at Los Alamos for deployment at Omega Upgrade, featuring a spherical radiation case and laser-entrance holes in a tetrahedral arrangement (see Figure 4). Because the unique mission of Omega Upgrade is direct drive, the beams enter the target chamber in a spherical geometry, a nonoptimal arrangement for cylindrical hohlraums. But tetrahedral hohlraums in Omega Upgrade can use all 60 beams and drive higher energy implosions than cylindrical implosions, an added advantage to the improved symmetry. The high illumination symmetry provided by tetrahedral hohlraums has been exploited in capsule implosion experiments described below.

There has been significant activity and progress in the area of hydrodynamic instability of imploding capsules. At NIF, capsules with cryogenic fuel will have to be compressed to large convergence ratios (above 30) in order to ignite. Convergence is ultimately limited by hydrodynamic instability. Until recently, laser-driven capsule implosions have only achieved moderate convergence ratios (below 10), attributed at least in part to the known limitations of past laser systems, including Nova, that had too few

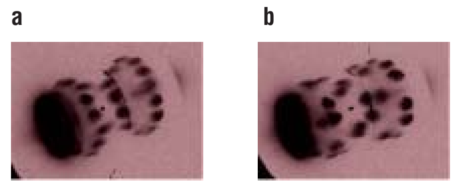

Figure 4. Cylindrical hohlraums with single-ring (a) and two-ring (b) configuration of beam spots. Experiments with such hohlraums are the first step in developing "beam phasing," in which many beams are arranged into multiple beam cones to control implosive symmetry.

beams to provide the desired capsule illumination symmetry. It was believed that once smoother hohlraum illumination became available, high-performance capsule implosions with significantly higher convergence would be straightforward to demonstrate. A series of experiments was carried out by P-24 personnel at Omega to compress capsules to convergence ratios of about 18 using tetrahedral hohlraums. In spite of the high illumination symmetry, the capsule neutron yield was degraded relative to corresponding calculations of ideal capsule implosions with no hydrodynamic mix in a manner similar to Nova capsules. These data are giving impetus to the development and testing of a novel mix model at Los Alamos.

P-24 hydrodynamics research has also focused on cylindrical implosion targets, which are much easier to diagnose than capsules and yet retain important convergent effects. P-24 researchers have completed a study of the nonlinear growth of multi-mode perturbations in x-ray-driven cylindrical targets due to the ablative Raleigh-Taylor (RT) instability on Nova, and the results were in good agreement with theoretical modeling. Moreover, there was spectacular success in deploying direct-drive cylindrical implosions of Los Alamos design, capable of significantly higher RT growth than the indirect-drive design. Our single-mode RT experiments on the new design showed significantly lower growth factors than predicted. A series of experiments with closely controlled but varying surface finish and imposed seed perturbations to test our theoretical understanding of these implosions is underway.

In collaboration with other groups in the Laboratory's Physics Division, Applied Theoretical and Computational Physics Division, as well as Oxford University, the University of California at San

Diego, Sandia, and Livermore, P-24 is using the Trident laser system to pursue studies of the dynamic properties of materials that are of interest to the ICF&RP program and to weapons science. The Trident laser is used to drive high-pressure (from tens of kilobars to several megabars), temporally shaped shocks into condensed materials under study. An exciting and novel alternative for driving dynamic materials experiments has been demonstrated recently on Trident. It uses a Trident beam in a relatively long pulse (>100 ns) to heat a plasma and drive smoothly a very flat flyer plate of ~2 mm diameter to velocities of a few kilometers per second. Using a flyer plate to shock materials makes a clear connection to conventional experiments in this field and avoids the potential drawbacks and questions associated with direct laser illumination of solids. Separate beams of the laser system can be used to create accurately synchronized, powerful x-ray and optical pulses that are used for probing the shocked material. Using this configuration, the group has developed and utilized novel diagnostic methods such as transient x-ray diffraction (TXD) and velocity interferometry (VISAR). TXD and VISAR have in turn been used to measure the dynamic properties of phase changes in materials. These experiments are being carried out both at Trident and at the Z pulsed-power facility, exploiting the novel capabilities for driving dynamic materials experiments recently developed there.

The experimental methods developed on Trident are being applied to materials of central interest to ICF, such as beryllium. One of the ultimate goals of this research program is detailed characterization of beryllium alloys such as beryllium-copper. These materials will be used as the ablator in advanced, Los Alamos-designed ignition capsules with superior hydrodynamic stability. Exact determination of the melt transition in these materials is crucial for predicting their hydrodynamic behavior during implosion. Initial experiments with available samples have already shown solid-solid phase transitions. Upon availability of samples with the necessary quality (including beryllium crystals), we intend to carry out a definitive study of phase transitions and melt in these materials in the pressure range of interest to ICF. Beyond phase transitions, we are studying other dynamic phenomena, such as spall, in various materials, including metals such as copper.

High-Energy-Density Experiments in Support of Stockpile Stewardship

P-24 performs laser and pulsed-power-based experiments that are intended to enhance understanding of the basic physical processes that underlie nuclear-weapons operation. In collaboration with weapons designers and other theoreticians, these experiments are designed to address issues in areas such as radiation hydrodynamics, fluid instabilities, shock-wave physics, and materials science. The experiments use the Trident laser, the Omega laser, the Helen laser at the AWE Laboratory in the UK, and Sandia's Z pulsed-power machine. We have formed strong world-wide collaborations in the disciplines central to high-energy density physics. Current work in the group includes

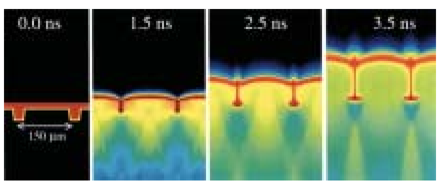

Figure 5. RAGE simulation of transverse view through the package showing the development of a 20-μm-wide spike, 30-μm tall above a 15-μm-thick back-plane CH-covered copper package at different times. The color scale represents the copper density from 0.1 g/cc in the low-density blow-off to 10 g/cc in the slightly compressed copper spikes and bubbles at 1.5 ns.

- studies of nonlinear evolution of hydrodynamic instabilities using planar and cylindrical targets driven by a variety of pressure sources (this includes the study of shock-driven turbulence using direct-laser-drive cylindrical targets at Omega);
- study of the implosion of cylindrical and spherical shells with various defects;
- topics in radiation hydrodynamics;
- imploding-liner studies of the basic nature of material friction;
- development and application of transient x-ray diffraction and other diagnostic techniques for the study of solid phase changes, plastic flow, and other materials phenomena;
- study (in collaboration with Sandia) of materials that are of interest for stockpile stewarship; and
- study of high-energy, laser-based x-ray radiography for diagnosis of hydrodynamic instability and radiation-hydrodynamic experiments.

It is worth highlighting one of these topics, which has been the subject of considerable effort in our group. We have performed a series of experiments on the Omega laser to test our predictive capability of the ablative RT instability as it evolves into the nonlinear stage dominated by thin spikes between thin bubbles. In these experiments, x-ray illumination (≈170–190 eV temperature) provided by spherical Omega hohlraums with tetrahedral illumnation symmetry have been used to accelerate planar copper targets with a preimposed perturbation. The normal difficulty with present-day facilities *(i.e.*, x-ray drive insufficient in strength and duration to drive RT beyond the linear phase) has been circumvented by imposing a nonlinear initial condition that resembles the bubble-spike structure expected in the late stages of RT evolution. The initial condition imposed on the RT target consists (in two dimensions [2-D]) of square spikes placed 150-μm apart, 30-μm high and either 10- or 20-μm wide. In reality, the spikes were ridges about 200 μm in length.

A flavor of the evolution of such a target is shown in Figures 5 and 6. Figure 5 shows a 2-D simulation with the RAGE code of the target with spikes initially 20-μm wide. Figure 6 shows experimental radiographs of the targets with spikes initially 10-μm wide. The simulation shows that the backing material flows in a way as to increase the length of the spikes. Therefore, a key figure of merit to compare between modeling and experiments is the height of the spikes above the backing surface. Our results agree qualitatively with the predictions from RAGE, but there are important differences presently under investigation. One difference is less spike growth than predicted. Another difference is that the strong predicted dependence on backing thickness is not observed.

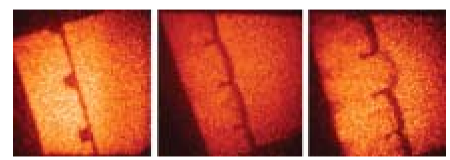

Figure 6. Radiographs taken with 6.7 keV x-rays of a driven target with spikes initially 20 μm in width and 30 μm in height above a 15-μm-thick back-plane. The target is overcoated with a 4 μm CH ablator layer of half normal density on the spike (left) side, which is the driven side. The times shown are (from left to right) 0, 2, and 3.4 ns relative to the beginning of the x-ray drive.

Magnetic Confinement Fusion

Magnetic fusion energy (MFE) research, and its associated science, is an important constituent of P-24's plasma physics portfolio. We are capitalizing on the recent strategic shift in national fusion research priorities to increase the emphasis on innovative fusion confinement approaches. To that end, we are working in P-24 with the Los Alamos MFE Program Office to develop new low-cost concepts for fusion energy. Central to this effort is MTF (magnetized target fusion), a truly different fusion concept intermediate in density between traditional magnetic fusion and inertial fusion. We specifically propose to form and preheat a compact toroid target plasma using well-established techniques and then compress this target plasma with imploding liner technology developed by DOE defense programs. A schematic of the proposed MTF machine is shown in Figure 7.

Three technical considerations explain why research in the MTF density regime is important. First, fusion reactivity, which scales as density squared, can be increased by many orders of magnitude over conventional MFE. Second, all characteristic plasma scale-lengths decrease with density. Hence, system size is naturally reduced at a high density. Third, magnetic insulation greatly reduces the required power and precision to compressionally heat a plasma to fusion-relevant conditions compared with ICF and brings the pulsed-power requirements for adiabatic plasma heating within reach of existing facilities. For more information, please read the research highlight "Magnetized Target Fusion" in Chapter 2.

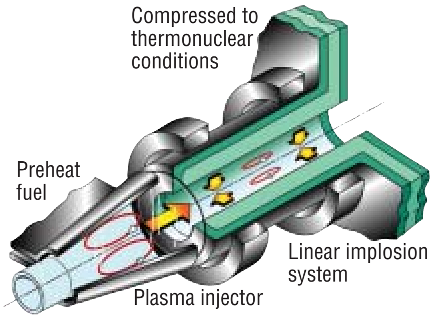

Figure 7. MTF will require us to create the initial plasma configuration, inject it axially into a flux-conserving shell, and finally compress the plasma to fusion-relevant density and temperature.

The future path for engineering development of MTF as an economic power source is less well-defined than for the more mature approaches of MFE and ICF. However, a number of possibilities are being discussed, and our research program will include scoping studies to identify the most promising approaches. If successful, MTF will achieve high performance fusion conditions with soon-to-be-realized pulsed-power facilities such as Atlas.

Historically, Los Alamos has had significant involvement in developing alternate approaches to fusion. This precedent has guided our development of collaborative programs with the National Institute for Fusion Science (NIFS) (Japan), the University of Washington, Livermore, and the Princeton Plasma Physics Laboratory. In all four collaborations, we employ our engineering, physics, and diagnostics expertise to aid the development of exciting moving fusion concepts.

Our collaboration with NIFS at the Large Helical Device (stellarator) involves the development of advanced imaging bolometry diagnostics. In collaboration with the University of Washington, we developed and fielded a 100-MW amplifier to drive plasma current in a field-reversed configuration (FRC) experiment by means of rotating magnetic fields. FRCs belong to the compact toroid class of fusion approaches and promise efficient magnetoplasma confinement with simple, compact reactor configurations. Our collaboration with the University of Washington on current-drive experiments are central to the notion of steady-state FRC operation.

With Livermore we are taking the next step in sustained spheromak confinement research. The Sustained Spheromak Physics Experiment, operating at Livermore, was designed to achieve high plasma performance under quasi-steady-state conditions. Los Alamos expertise, developed over years of research on the Compact Torus Experiment spheromak, will be an important contributor to the success of this effort. We are also members of the national research team on the National Spherical Torus Experiment, operating at the Princeton Plasma Physics Laboratory. This experiment investigates the confinement properties of very low-aspect-ratio tokamaks with a view to achieving efficient (high-beta) confinement in a compact toroidal system. At the National Spherical Torus Experiment, we are focusing on fast imaging of visible light turbulence in the edge of the plasma, as well as observations of general phenomena during helicity injection current drive

Applied Plasma Technologies

P-24 develops and uses advanced plasma science and technology to solve problems in the areas of defense, the environment, and industrial manufacturing. The group has achieved international status and recognition in this pursuit in recent years, including three R&D 100 awards. The first R&D 100 award, presented in 1996, was in recognition of the development of the PLASMAX system, which takes advantage of plasma sheath properties combined with mechanical vibration to rapidly and effectively clean semiconductor wafers without water or other liquid solvents. The second R&D 100 award, presented in 1997, recognized the efforts of a multidisciplinary group (both Laboratory and industrial personnel) in the initial commercialization of plasma source ion implantation (PSII). More recently, our efforts have concentrated on the development of the atmospheric-pressure plasma jet (APPJ, described below), for which an R&D 100 award was granted in 1999 and a patent was just granted to the University of California in February 2001.

Atmospheric-Pressure Plasma Jet

A nonthermal, uniform-glow discharge at atmospheric pressure in a cylindrical cavity with high gas-flow rates produces reactive chemical radicals and metastables persisting for fractions of a second at atmospheric pressure. These reactive species remove surface contaminants and films, providing a new means of cleaning objects and substrates (see Figure 8). Current programs include chemical and biological decontamination for the neutralization of chemical agents on surfaces and graffiti removal. We have also been working on improving further the operation of the APPJ. One recent success has been the ability to decrease significantly the necessary fraction of helium in the feed gas to maintain acceptable operation. This development promises to decrease the cost of APPJ-based processing for many applications where very large surface areas are to be treated.

For more information, please read the research highlight “Materials Processing using an Atomospheric-Pressure Plasma Jet” in Chapter 2.

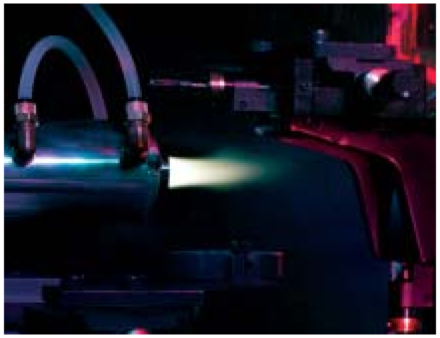

Figure 8. The atmospheric-pressure plasma jet in operation, with a reactive gas stream exiting from the source.

Atlas

Atlas is a 24-MJ, 30-MA advanced pulsed-power facility that was completed in late 2000. Now that the pulsed-power driver, the major part of the facility, has been finished, attention has shifted to completing the power-flow system that delivers the driver energy to the load (*i.e.*, the experimental packages of interest). P-24 has been involved in several aspects of the physical design of Atlas, including primary responsibility for the power-flow system. P-24 has been also involved in defining and designing the experimental agenda for the first several years of operation, developing advanced diagnostics to be fielded on these experiments, and fielding experiments on Pegasus and Ranchero to prepare for Atlas operation.

The Atlas Physics Design Team, which includes P-24 staff, has developed the list of the types of experiments to be fielded in the first 200 shots (the first two years of Atlas operation). This experimental program relies on the capability of Atlas to implode 40-g cylindrical liners at velocities of up to 20 km/s on timescales of several microseconds. Such implosions will produce material pressures of several tens of megabars, magnetic fields up to 1,000 T, material strain rates of 10^6 s^{-1}, and strongly coupled plasmas of nearly solid densities at temperatures of several electron volts. Included on this program are experiments to investigate Rayleigh-Taylor mix, Bell-Plesset deformation of the liner, friction at high relative velocities, on-hugoniot equation-of-state (EOS) measurements, calibration of the Nevada Test Site nuclear impedance-matching EOS experiments, multiple-shock EOS, quasi-adiabatic compression of materials, release isentropes, high-strain-rate phenomena, dense-plasma EOS and transport, hydrodynamics and instabilities in strongly coupled plasmas, magnetized target fusion (MTF), and high magnetic field generation. Specific experimental campaigns are now being designed to determine the diagnostic and experimental configuration requirements. As part of a successful Laboratory Directed Research and Development proposal, we have been assisting in the development of a variety of advanced diagnostics to be fielded on Atlas, including linear and nonlinear optical techniques, x-ray diffraction, photoelectron spectroscopy, and flash neutron resonance spectroscopy. All of these techniques are well developed for steady-state measurements, and the development effort lies in adapting them to the dynamic Atlas environment.

Further Information

For further information on all of P-24's projects, refer to the project descriptions in Appendix A. Some of our major achievements are also covered as research highlights in Chapter 2. These include our work in the area of LPI, cylindrical and spherical implosion research at Nova and Omega, MTF research and results, and the continued development of the APPJ.